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Title: MCNP6 Cosmic-Source Option

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ABSTRACT

MCNP is a Monte Carlo radiation transport code that has been under development for over half a century. Over the last decade, the development team of a high-energy offshoot of MCNP, called MCNPX, has implemented several physics and algorithm improvements important for modeling galactic cosmic-ray (GCR) interactions with matter. In this presentation, we discuss the latest of these improvements, a new Cosmic-Source option, that has been implemented in MCNP6.

MCNP6 Cosmic-Source Option

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Outline

- **Introduction**
- **Cosmic-source option**
- **Benchmark results**
- **Terrestrial backgrounds**
- **Conclusions**

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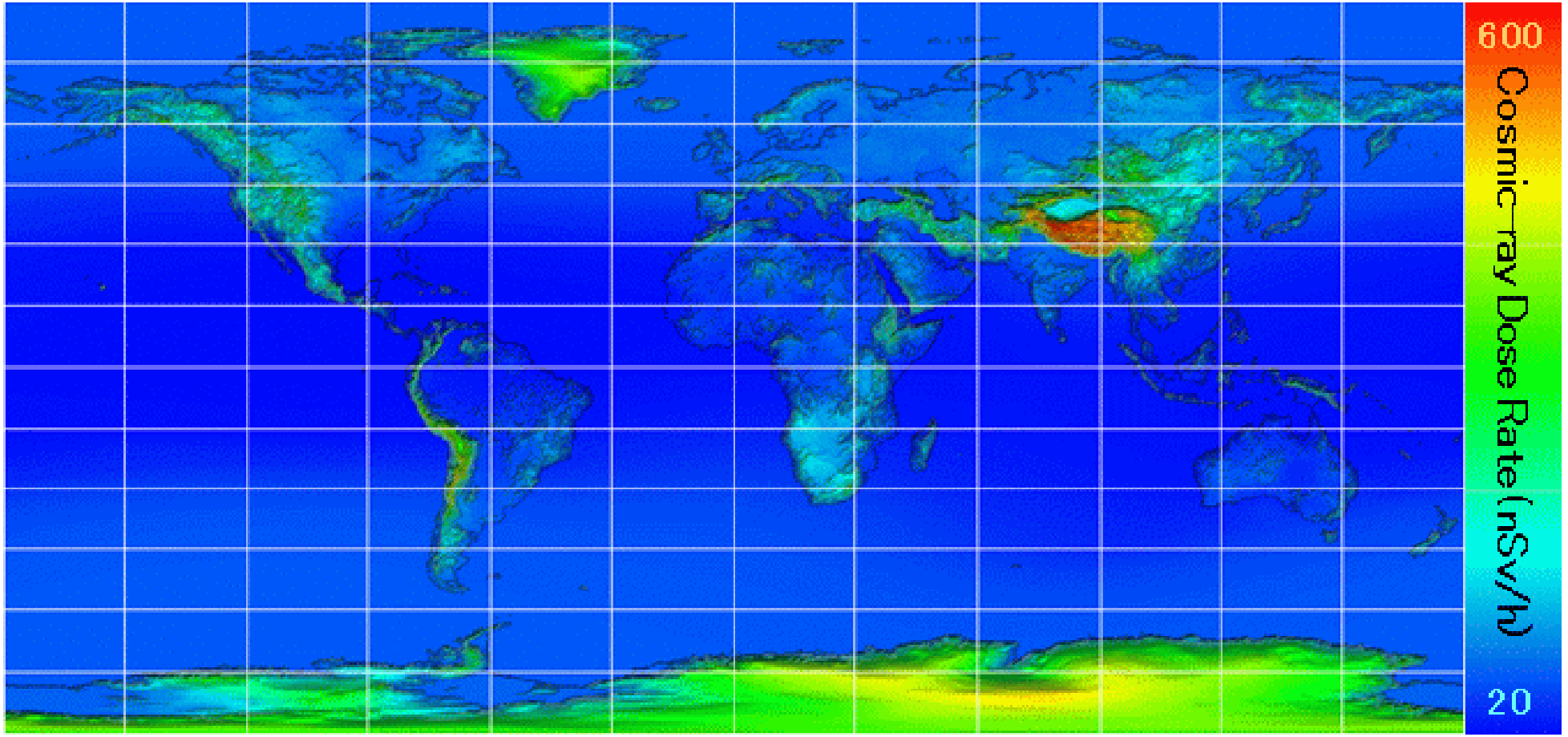
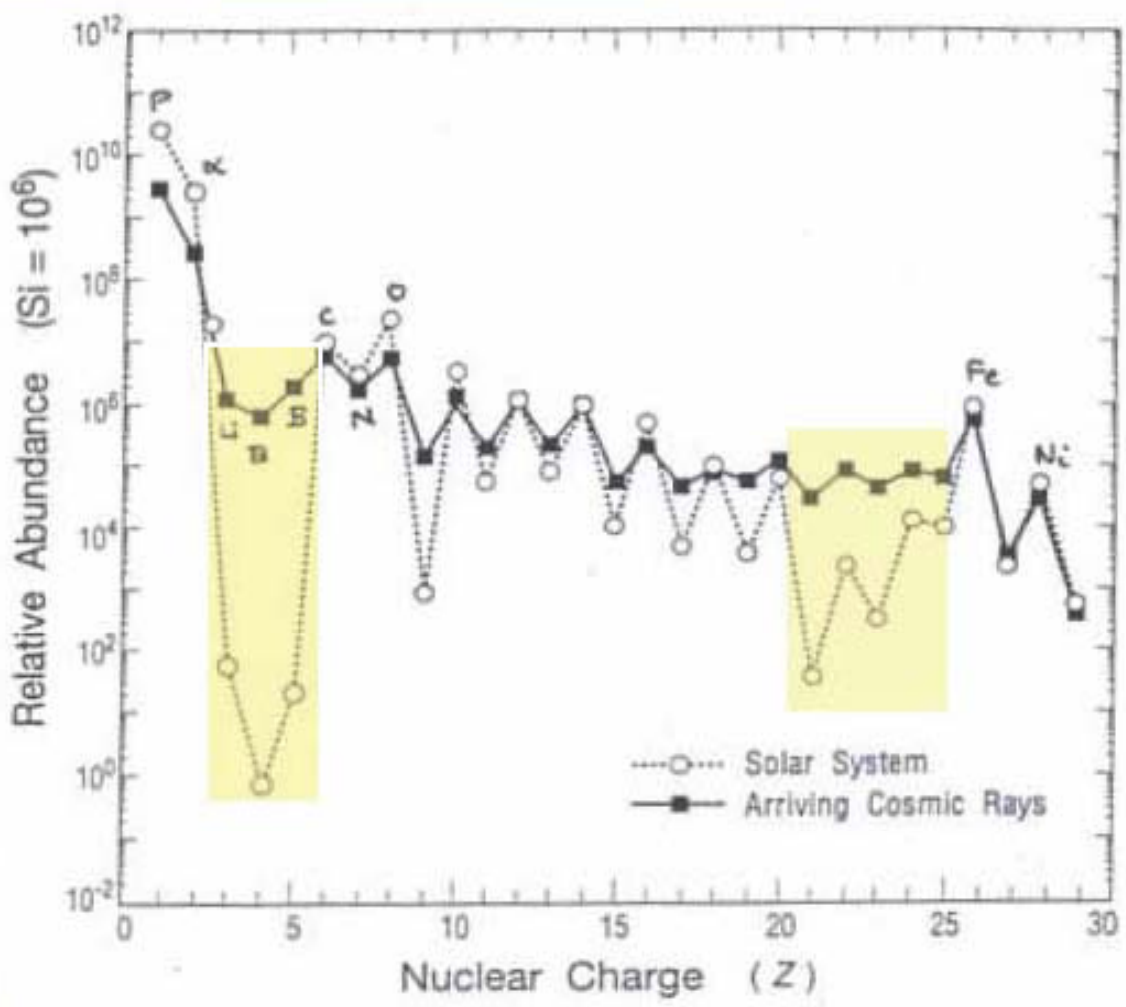
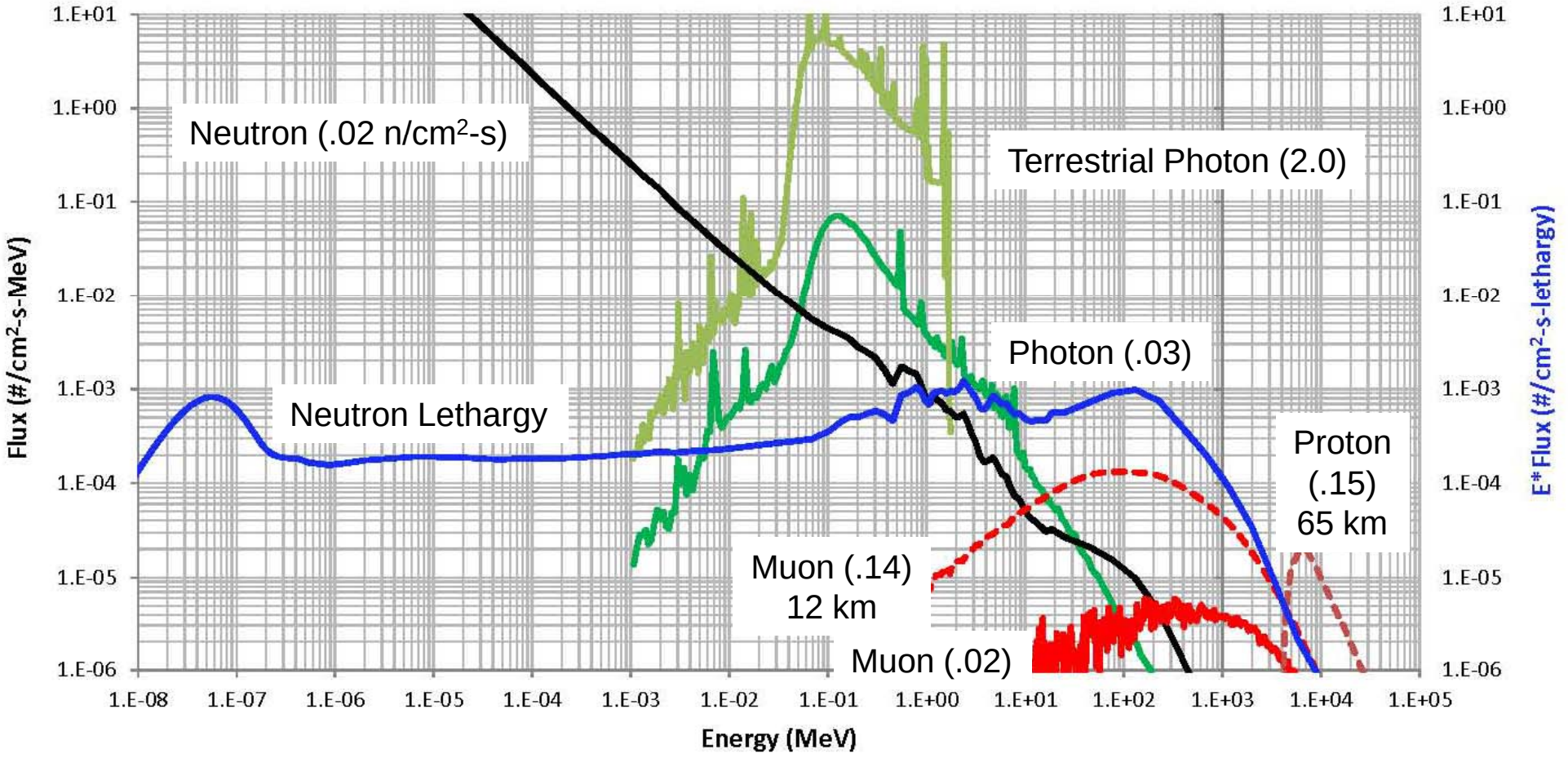
Neutron & gamma GCR background spectra show a strong dependence on longitude, latitude, and altitude



GCR composition – initial MCNP6 implementation includes protons and alphas

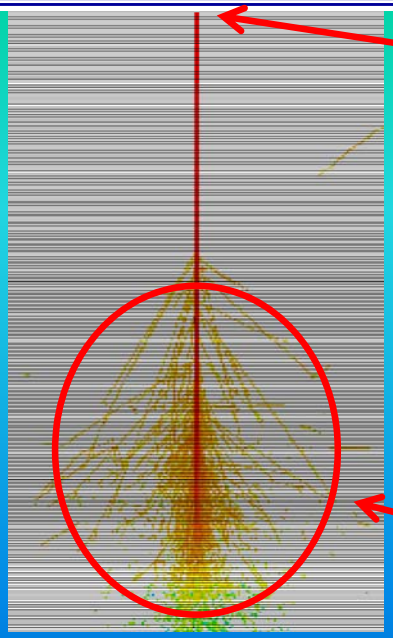


GCR induced neutron and photon spectra at sea level (Livermore, CA)



Collaborations are underway to provide a predictive world-wide background capability

Cosmic Radiation



"Sky Maps" of protons, alphas, etc. versus long. & lat.
(U of Del. – John Clem)

Detailed cosmic ray model (300 layers of atmosphere)
(MCNPX)

Cosmic neutron benchmark measurements from Long Dwell program
(NUSTL – Paul Goldhagen)

NORM Spectra - K, Rb, Th, U
(MCNPX)

Terrestrial Radiation

Cosmic-source option – two GCR spectra (interplanetary, geomagnetic) and 3 new SDEF source keywords

- **Built-in spectra**
  - Historic (PRL/Lal, 1980)
  - Modern (UoD/Clem, 2006)
- **User interface**
  - PAR keyword enhanced
  - New keyword LOC
  - New keyword DAT
- **Benchmarking (NUSTL/Goldhagen collaboration)**
  - Atmosphere (primary spectra, soon)
  - Atmosphere (secondary spectra ~120^{o}W, June 1997)
  - Ground (NY, Nov. 2001, soon; CA, Nov. 2006)

Interplanetary spectrum proposed by Devendra Lal, combined with rigidity cutoffs

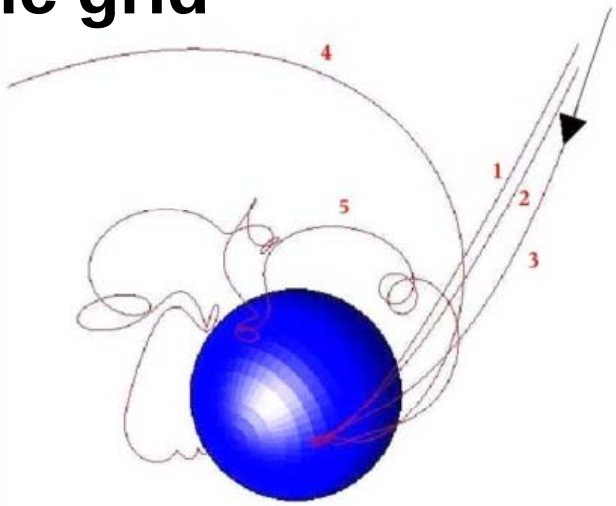
- **Intended for interplanetary use**
  - See Apollo 17 benchmark paper (McKinney et al., JGR, 2006)
- **Analytic form of the 4π differential spectra**

  $g(T,\phi) = A\ T\ (T+2E_0)\ (T+m+\phi)^{-\gamma} / [(T+\phi)\ (T+2E_0+\phi)]$

  g = particles/cm^2-s-MeV
  T = kinetic energy per nucleon (MeV/n)
  ϕ = solar modulation potential (MV)
  E_0 = rest energy of a nucleon (MeV)
  m = a exp(-bT)
  A, a, b, γ are fitting parameters (different for each particle)
- **Apply Clem rigidity cutoffs for geomagnetic use**
  - Truncates low-energy portion of Lal spectra

Geomagnetic spectra proposed by John Clem, uses skymaps describing rigidity parameters

- **Intended for geomagnetic use**
  - Has a built-in interplanetary spectrum (zero rigidity)
- **Skymaps generated on a geomagnetic grid**
  - Provides rigidity cutoffs versus polar & azimuthal angle
  - Separate set of maps for various altitudes
  - Monte Carlo code provides light & heavy ion spectra (Z>2)



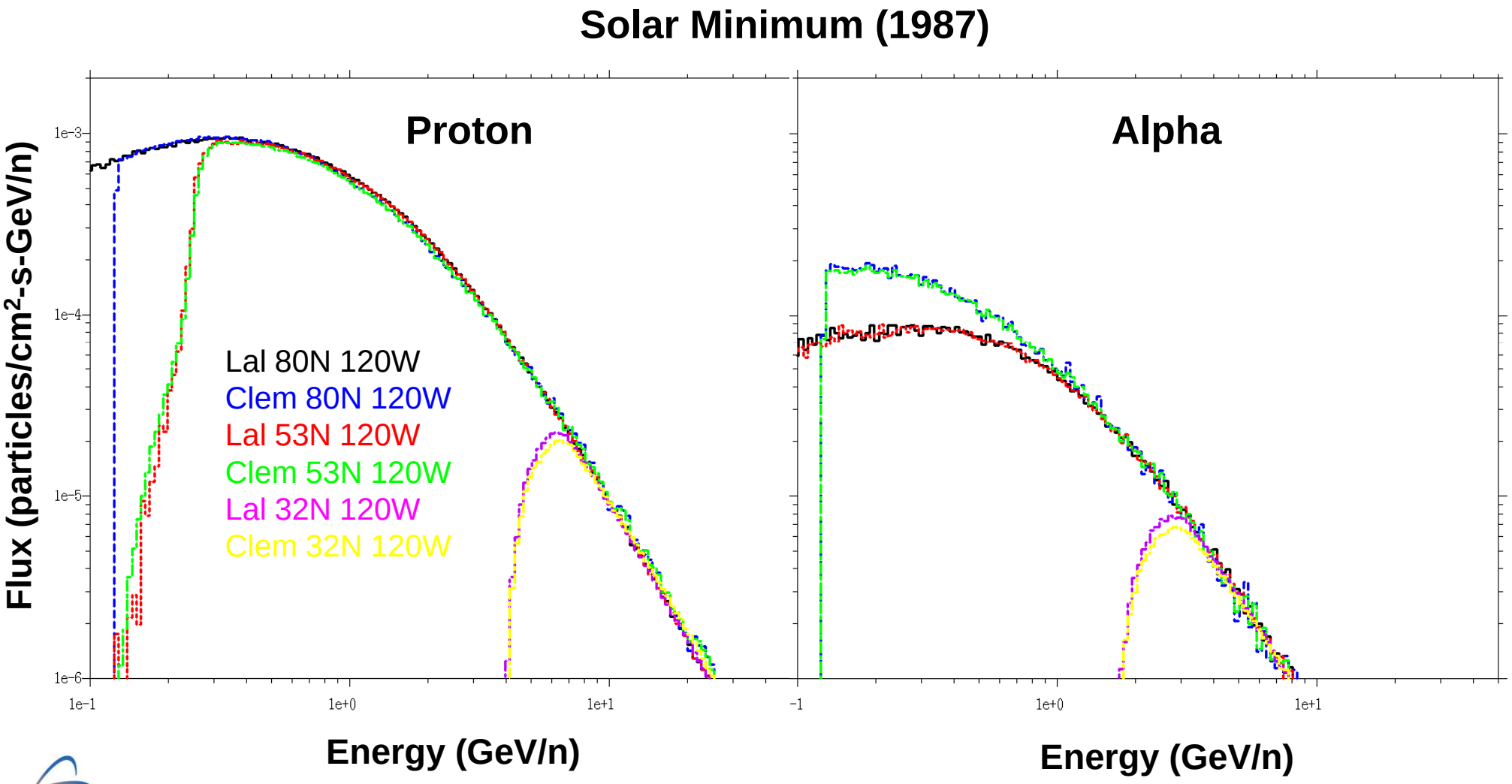
- **MCNP6 includes a link to the BRI UoD code**
  - Skymap data condensed on 5^{o} lat., 20^{o} long. grid (at 65 km)

MCNP6 user interface – three new SDEF keywords

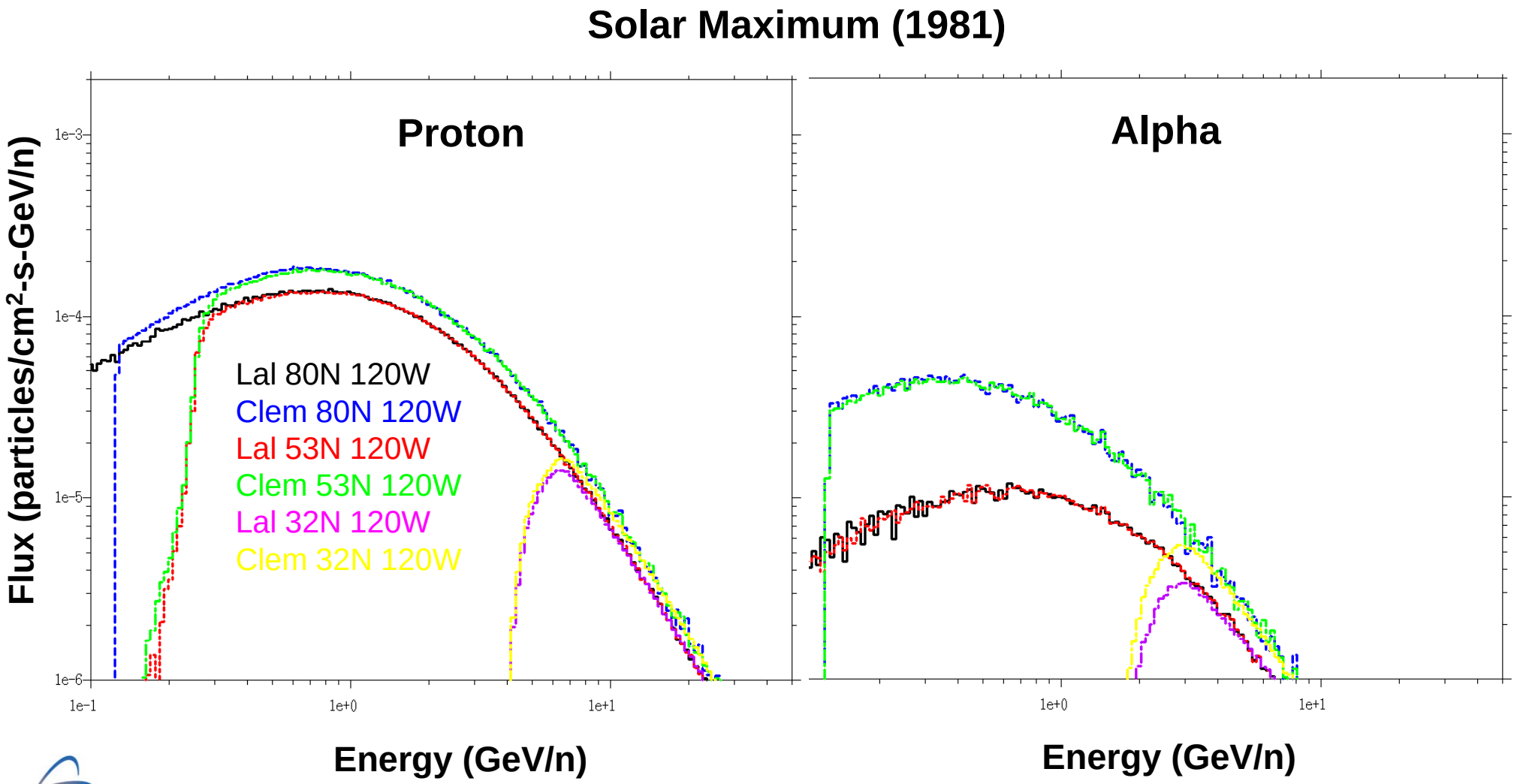
```
Clem Cosmic Source for Solar Max.
1 0   -1  2  imp:n=1
2 0   -1 -2  imp:n=1
3 0    1     imp:n=0

1 rpp -1000 1000 -1000 1000 -1000 1000
2 pz 999

mode n h a
SDEF X=d1 Y=d2 Z=999.1 VEC=0 0 -1
     PAR=CR DAT=1 1 1987 LOC=80 -120 65
si1 -1000 1000
sp1 0 1
si2 -1000 1000
sp2 0 1
phys:h,a 1e6
nps 1000000
print
f11:h 2
f12:h 2
fm12 4E6
f21:a 2
f22:a 2
fm22 4E6
e0 1 349ilog 1e6
c  dbcn 31j 1  $ Use Lal spectra
```

Description of SDEF keywords.		
Keyword	**Values**	**Description**
PAR	[-]cr [-]ch [-]ca	All cosmic particles Cosmic protons Cosmic alphas
DAT	M D Y	Month (1-12) Day (1-31) Year (4 digit)
LOC	P A H	Latitude (-90 to 90; S to N) Longitude (-180 to 180; W to E) Altitude (km)

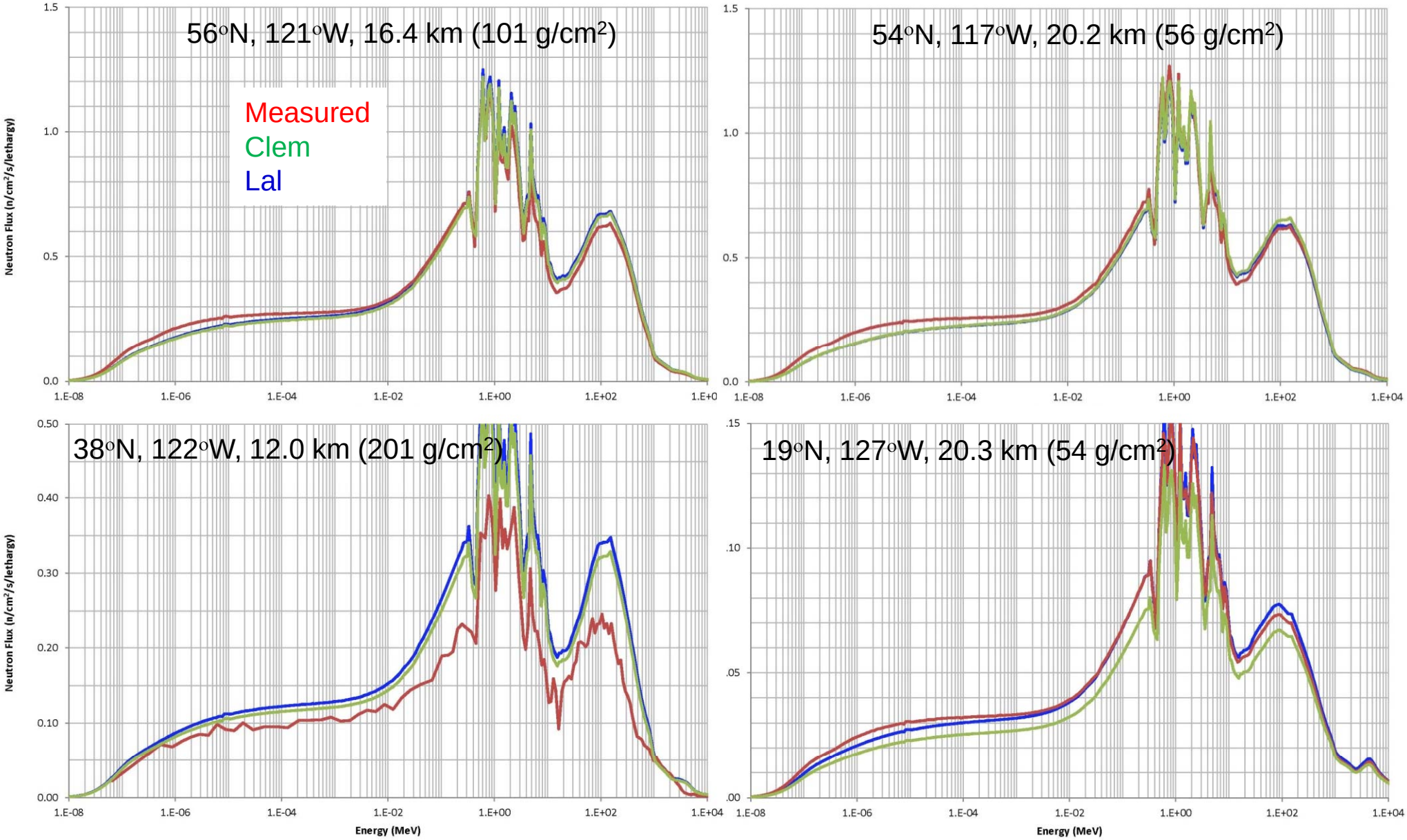
Top-of-the-atmosphere proton and alpha spectra at various longitudes and latitudes – solar minimum



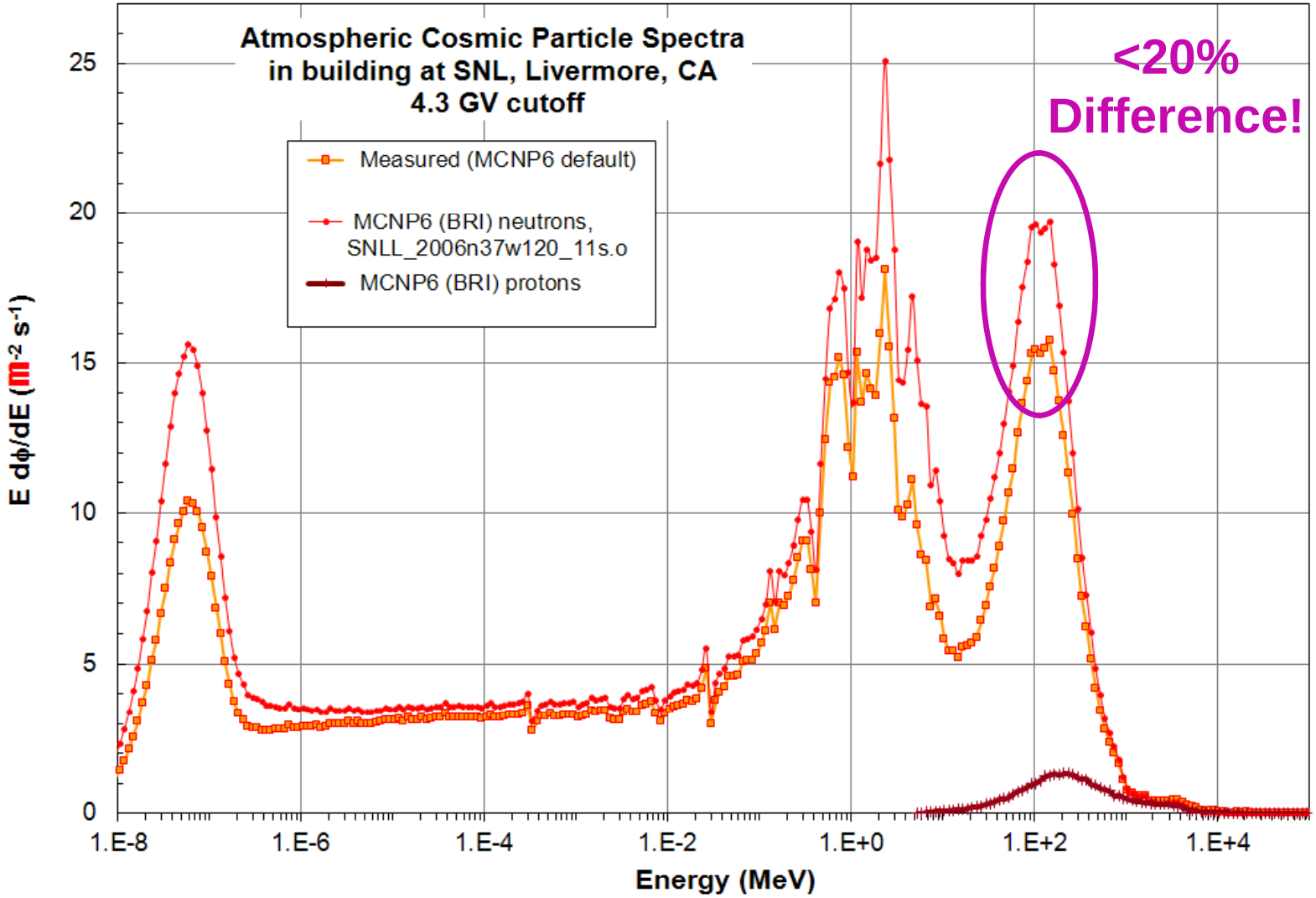
Top-of-the-atmosphere proton and alpha spectra at various longitudes and latitudes – solar maximum



Neutron spectra compared to measured data – NASA flights over western Canada, CA, and west of Mexico

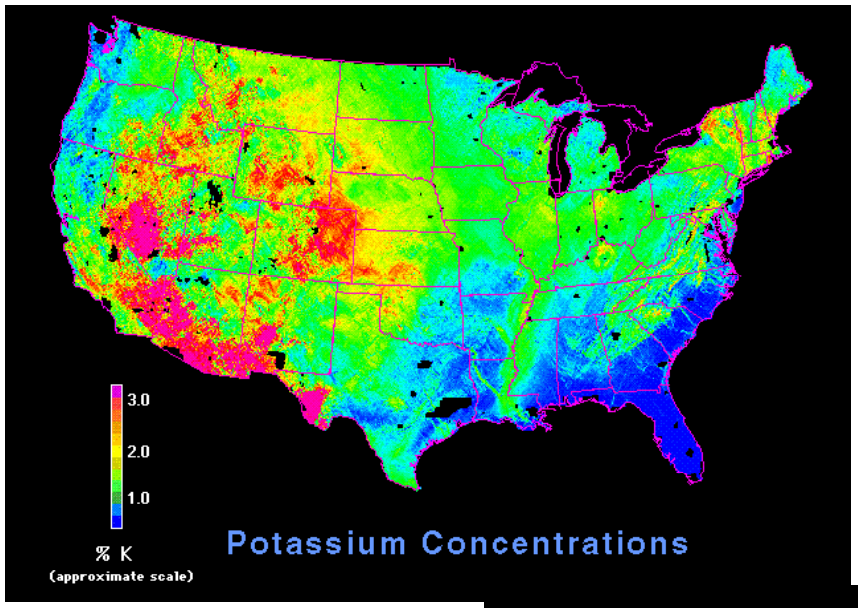


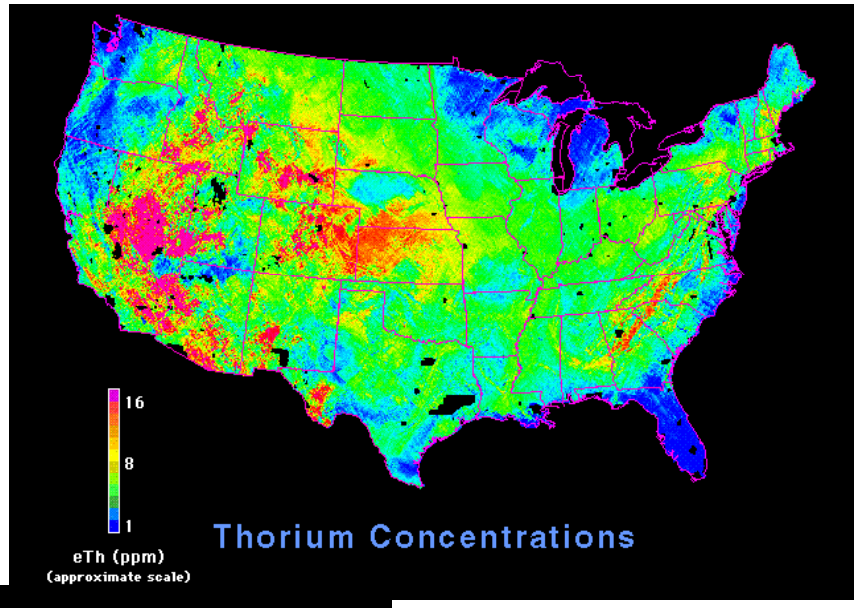
Neutron spectra compared to measured data – Livermore, CA, November 2006

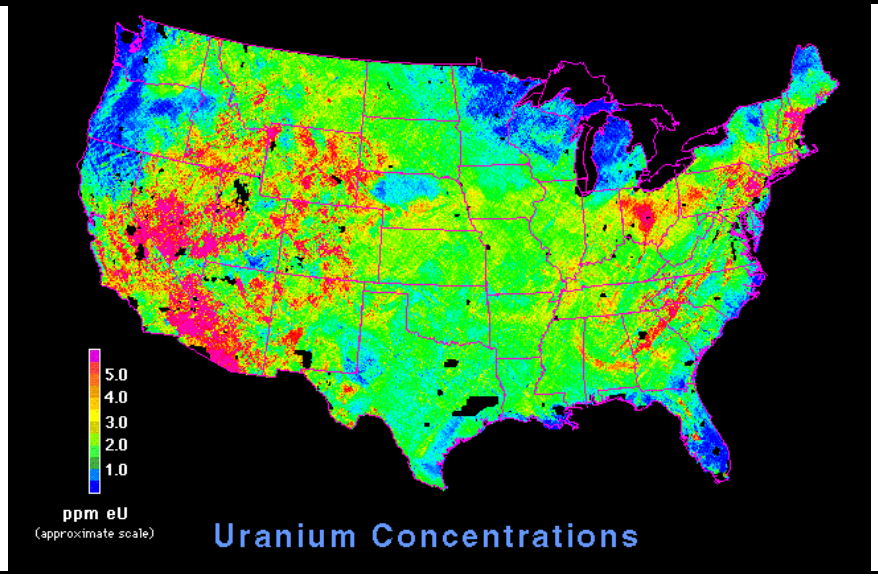


Neutron spectra compared to measured data – ongoing
New York, NY, November 2001 and 2012

Terrestrial radionuclide concentrations will be taken from USGS maps – initially using a 10ºx10º long./lat. grid







Simple example of radionuclides in a wet porous soil (Livermore, CA) – tally photon flux above the ground

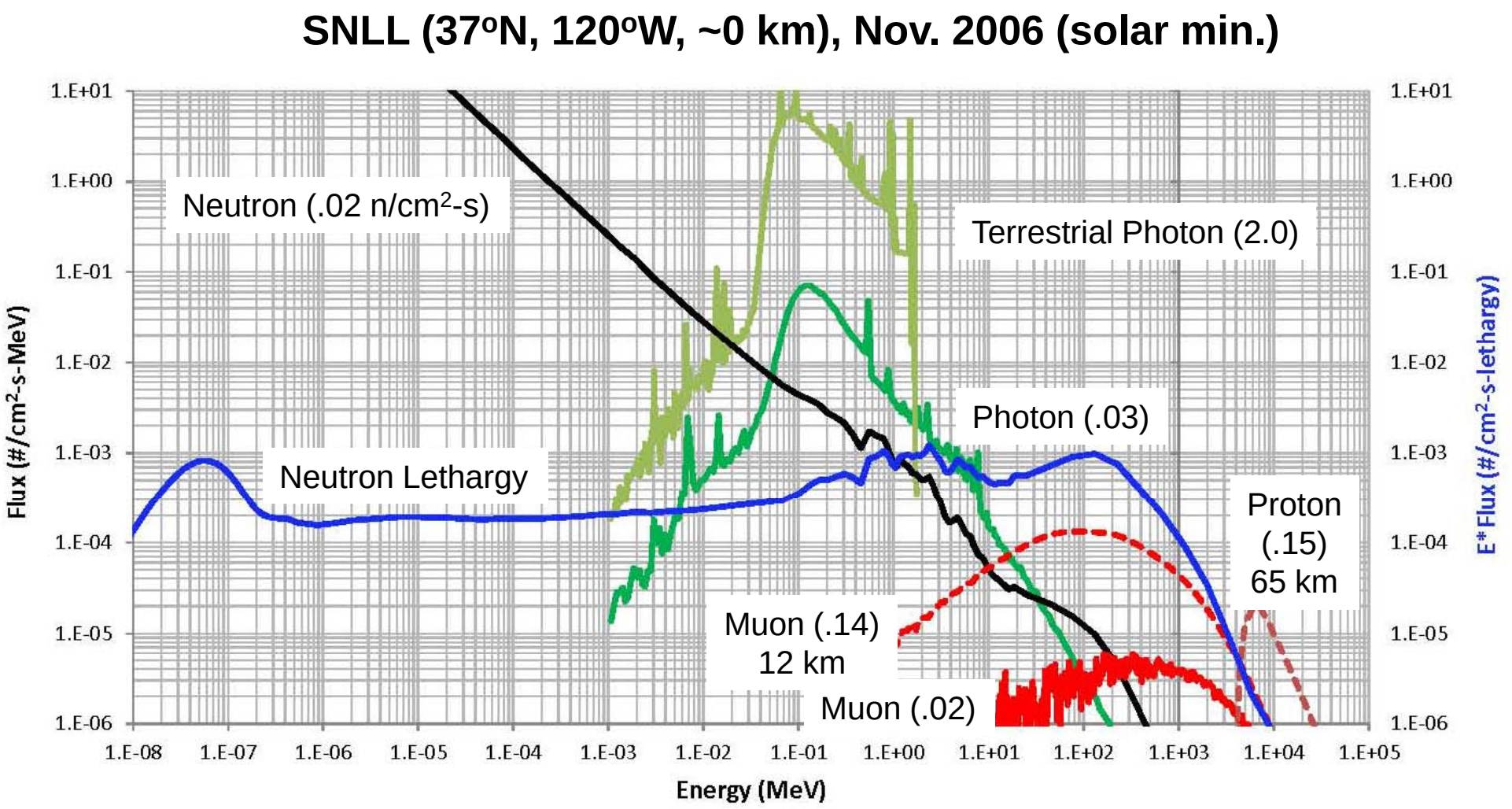
```
Terrestrial background for 37N 120W
1  1  -1.4000       1  -2  -5   imp:p=1
2  2  -0.00120698   2  -3  -5   imp:p=1
3  2  -0.00120698   3  -4  -5   imp:p=1
4  0                5:-1:4       imp:p=0

1  pz  0.0
2  pz  100.0
3  pz  200.0
4  pz  10000.0
5  cz  1000.0

mode p
act  fission=none nonfiss=p dg=lines
m1    8016 -.58457 $ Wet porous soil
     14028 -.18944
     14029 -.00962
     14030 -.00634
     13027 -.06026
     26054 -.00217
     26056 -.03400
     26057 -.00079
     26058 -.00010
      1001 -.03013
     20000 -.02691
     11023 -.02098
     19000 -.01920
     12000 -.01549
     19040 -2e-6 $ 2 ppm
     90232 -5e-6 $ 5 ppm
     92238 -2e-6 $ 2 ppm
m2   $ Air with 60% humidity
      7014   -.729981
      8016   -.256290
     18000   -.012374
      1001   -.001360
sdef  par=sp  wgt=2.5e8
      pos=0 0 0 axs=0 0 1 rad=d1 ext=d2
si1  0 1000
sp1  -21 1
si2  0 100
sp2  0   1
f4:p  2
e4    1e-3 299log 10
nps  1000000
print
```

Terrestrial photon flux combined with cosmic photon flux on a 10ºx10º grid within the MCNP6 “background.dat” file

```
Neutron flux from Goldhagen JEDEC No. 89A (2006)Photon flux from MCNPX
           90.0             0.0             0.0       183
 flux (n/cm2/s)     0.1193E-01 flux (p/cm2/s)     2.0000E+00
     1.0593E-10     2.1270E+02     1.0354E-03     2.5895E-05
     1.1885E-10     2.3849E+02     1.1087E-03     1.3244E-05
     1.3335E-10     2.6743E+02     1.1872E-03     5.5672E-05
     1.4962E-10     3.0003E+02     1.2712E-03     2.5714E-05
     1.6788E-10     3.3624E+02     1.3612E-03     1.1886E-05
     1.8836E-10     3.7715E+02     1.4576E-03     5.1054E-06
     2.1135E-10     4.2306E+02     1.5608E-03     3.8590E-05
                                ...
                                   1.6937E+01     7.4518E-05
                                   1.7575E+01     5.2691E-05
                                   1.8237E+01     6.4417E-05
                                   1.8924E+01     5.0422E-05
                                   1.9637E+01     4.4057E-05
                                   2.0797E+01     5.4823E-05
Neutron flux from Goldhagen JEDEC No. 89A (2006)Photon flux from MCNPX
            0.0             0.0             0.0         0
 flux (n/cm2/s)     0.6995E-02 flux (p/cm2/s)     2.0000E+00
Neutron flux from Goldhagen JEDEC No. 89A (2006)Photon flux from MCNPX
            0.0            10.0             0.0         0
 flux (n/cm2/s)     0.6914E-02 flux (p/cm2/s)     2.0000E+00
Neutron flux from Goldhagen JEDEC No. 89A (2006)Photon flux from MCNPX
            0.0            20.0             0.0         0
 flux (n/cm2/s)     0.6828E-02 flux (p/cm2/s)     2.0000E+00
                                ...
```

Terrestrial + Cosmic

Predicted background spectra for all particles at sea level (Livermore, CA)



Conclusions

- **MCNP6 can provide realistic world-wide cosmic & terrestrial background spectra, which can be combined with other standard sources**
- **Benchmarking of these capabilities will continue**
- **Incorporation of cosmic & terrestrial spectra into the "background.dat" file will continue (10^{o}x10^{o} grid) to facilitate its use in analyses of nuclear systems**
- **Future upgrades include:**
  - **Heavy-ion GCR**
  - **Altitude dependence**
  - **Improved interpolation of "background.dat" spectra**
  - **Additional cosmic spectra (proton, alpha, muon, pion, etc.)**
  - **Improved geomagnetic grid (more data where changes are large)**